A Modeling Study of Coastal Sediment Transport and Morphology Change

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ABSTRACT

Damon Point in Grays Harbor has experienced continued evolution towards the existing navigation channel and the land intrusion into the harbor posts potential threat to navigation and port operation. Numerical modeling study was conducted to investigate the hydrodynamics, sediment transport, and morphology change at the harbor near the navigation channel. Calculated waves, currents, water levels, sediment transport and long term morphology changes were calibrated and validated with the field measurements. Hydrodynamic and morphodynamic analysis indicates that sediment transport due to the land evolution will not result in significant depth changes in the nearby channel in the next 5 years.

KEY WORDS: Navigation channel; numerical modeling; waves; current; water level; sediment transport; morphology change.

INTRODUCTION

Grays Harbor estuary is located on the southern coast of Washington, USA. The Chehalis River flows into the system from the east and a large natural inlet on the west connects the harbor to the Pacific Ocean. The deep draft federal navigation channel is 39.1 km long and leads from the Pacific Ocean to Cow Point located on the Chehalis River. The channel is 300 m wide outside the inlet and narrows to 100 m near the Port of Grays Harbor at Cow Point (Fig. 1).

In recent years Damon Point on the northeast portion of the harbor entrance has experienced continued evolution towards the existing navigation channel. The elongation of Damon Point, a spit located east of the north jetty, has caused the channel thalweg to migrate south-east. Spit encroachment on the navigation channel may lead to increased maintenance requirements.

The purpose of this study is to develop and calibrate a hydrodynamic and sediment transport model of the Grays Harbor estuary. The model will be used to evaluate potential shoaling in the navigation channel and its possible link with the growth of the Damon Point spit. Additionally, several hypothetical simulations are performed to investigate physical consequences of the Damon Spit encroachment and associated channel migration.

Fig. 1. Grays Harbor estuary.

Following the Introduction of this paper, the field data collection is described in Section 2. Section 3 provides information on modeling methodology. Section 4 presents model results for the calibration and projection simulations, and Section 5 gives the conclusions of the study.

DATA COLLECTION

A field data collection program was conducted in September 2010 (Golder, 2010). Waves, water levels, currents, and sediment data were collected in the region of Damon Point and were used for model calibration and validation, and for understanding the long term dynamic changes occurring at the entrance to Grays Harbor. Components of the data collection program include:

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14. ABSTRACT
Damon Point in Grays Harbor has experienced continued evolution towards the existing navigation channel and the land intrusion into the harbor posts potential threat to navigation and port operation. Numerical modeling study was conducted to investigate the hydrodynamics, sediment transport, and morphology change at the harbor near the navigation channel. Calculated waves, currents, water levels, sediment transport and long term morphology changes were calibrated and validated with the field measurements. Hydrodynamic and morphodynamic analysis indicates that sediment transport due to the land evolution will not result in significant depth changes in the nearby channel in the next 5 years.

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- Two Surf and Intertidal Dynamics Sensor Platform (SIDSEP) Beach Pod installations for nearshore waves, current, and suspended sediment monitoring;
- Bottom mounted Acoustic Doppler Profiler (ADP) for currents and waves;
- Beach topography survey and nearshore bathymetry survey.

Fig. 2 shows the location of the two Beach Pods, ADV265 and ADV210, at the midpoint and near the distal end of the Damon Point spit, respectively. The bottom-mounted ADP, ADPM135, was deployed near the midpoint of Damon Point at approximately 7.5 m depth approximately 1.5 km offshore. This instrument with a pressure sensor measured current, water surface elevation, and wave parameters. The bathymetry and topography surveys were conducted using a combination of water based (Jet Ski) and traditional terrestrial techniques (RTK GPS). The survey repeated and expanded on a previous survey performed in 2002 and is used to provide measured morphology change.

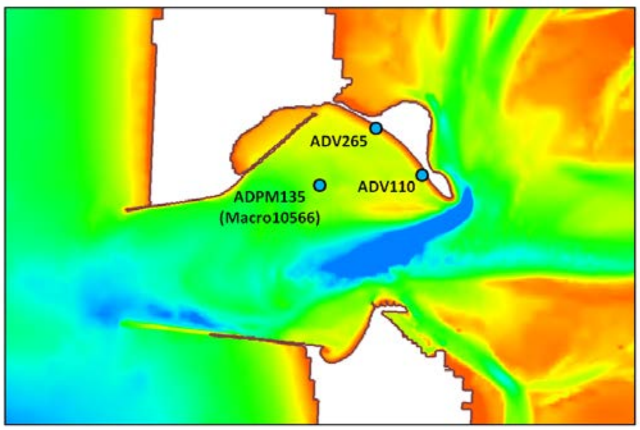

Fig. 2. Locations of beach pods and ADP gauge.

Bathymetry used to configure the numerical model was a combination of survey data collected by USACE Seattle District (NPS), and NOAA NOS data. The NPS data include the most up-to-date surveys in the navigation channel, Half Moon Bay as well as near Damon Point, which were given priority over the NOS data. Fig. 3 shows an image of the bathymetry near Damon Point including the navigation channel.

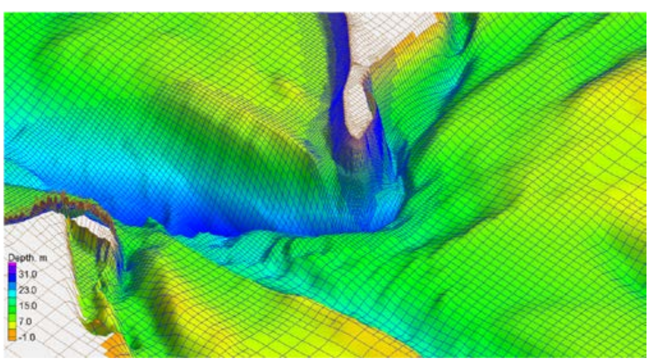
Fig. 3. Bathymetry near Demon Point.

For the model forcing, measured water levels were retrieved from NOAA Westport tidal gauge (9441102) and the tidal phase was adjusted based on the distance between this gauge and the model open boundary. Wave and wind data were obtained from NDBC buoy 46029, located approximately 87 km south west of Grays Harbor.

METHODOLOGY

Coastal Modeling System

The CMS is a suite of PC-based numerical hydrodynamic, wave, and sediment transport models consisting of CMS-Flow, CMS-Wave, and CMS-PTM (CIRP, 2010). The CMS is interfaced through the Surface-water Modeling System (SMS). Fig. 4 shows a schematic of CMS operation and included coastal processes.

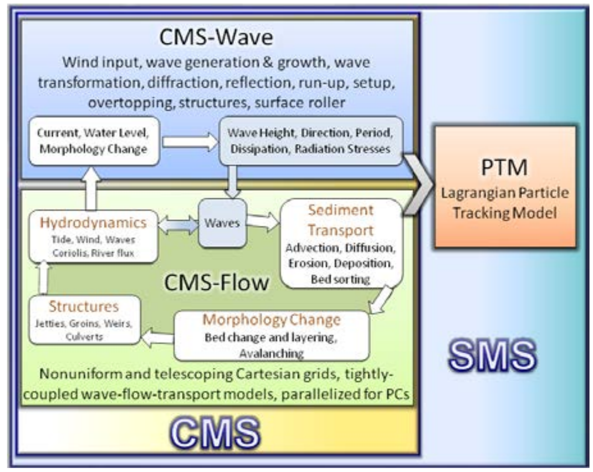

Fig. 4. CMS schematic.

CMS-Flow uses a finite volume method which fully conserves mass. Physical processes calculated by CMS-Flow are circulation, sediment transport, and morphology change. Several sediment transport formulations are implemented in CMS-Flow, including the equilibrium total load, the equilibrium bed load plus advection-diffusion and suspended load, and the non-equilibrium total load (Sanchez et al., 2011ab).

CMS-Wave is a finite difference spectral wave transformation model that contains approximations for wave diffraction, reflection, wave transmission, wave run-up, and wave-current interaction. Processes specific to inlet and harbor applications include forward and backward wave reflection, wave overtopping and transmission through rubble mound structures, and run-up (Lin et al., 2011).

Model Configuration and Set Up

A telescoping grid was developed for the CMS. The domain of this grid covers approximately 25 km alongshore and 20 km cross shore distance from the offshore boundary. The grid also covers 30 km into the embayment measured from the jetties for a total coverage area of 1,100 km^2. The grid contains 57,000 computational cells ranging from 7.5 x 11.25 m to 480 x 720 m. Additional refinement was added around the north and south jetties as well as Half Moon Bay, Damon Point and the tidal channels that exist in the main embayment of Grays Harbor. Fig. 5 shows the grid domain in the top panel and the grid refinement near Damon Point and the jetties in the bottom panel. Warmer colors indicate shallower water depths while cooler colors indicate deeper depths.

The model validation was conducted for two simulation periods. To evaluate model calculations of water levels, currents, and waves, the CMS was set up corresponding to the most recent field data collection over 30 days starting 3 September 2010. For the demonstration of morphology performance a 9-month simulation from 1 June 2009 to 26

February 2010 was set up, which corresponds to a measured post-dredge to pre-dredge morphologic period.

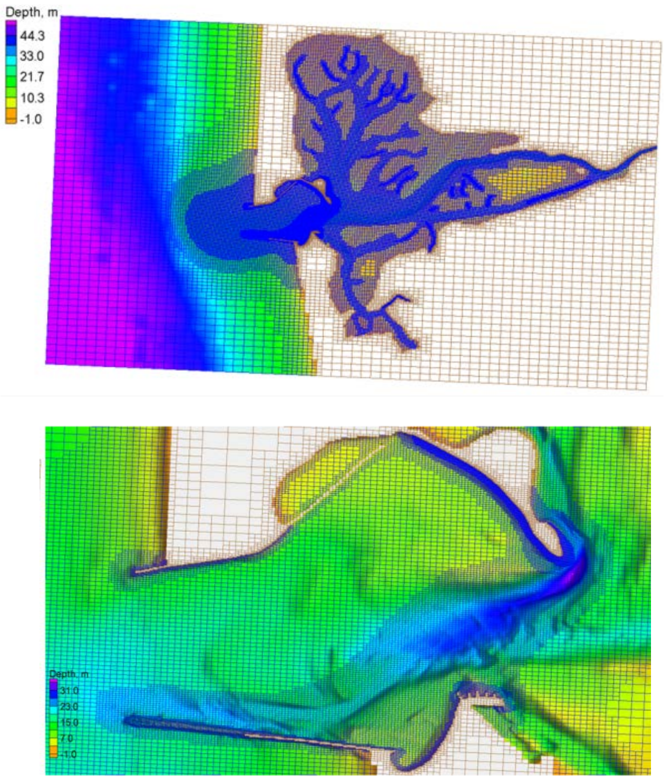

Fig. 5. The telescoping grid and refinement near Demon Point.

Hydrodynamic and sediment transport ramp time was set at 0.25 days with a 15 minute time step. The water surface elevation measured at the NOAA Westport gauge was used for offshore boundary condition. A phase offset was included to account for the distance between the gauge and the offshore boundary. Wave spectra were developed from the CDIP buoy located approximately 9 km offshore in 40 m water depth. Winds were taken from NDBC 46029 located approximately 90 km SSW from the site in 135 m water depth.

Grain sizes vary widely in the estuary presenting challenges for sediment transport models. Fig. 6 show the range in grain sizes from all available sediment samples with relation to the ocean regions, the entrance channel and Damon Point. Grain sizes show an increasing size trend moving from the ocean to Damon Point. While this general behavior is expected, the relative coarseness of grains found at Damon Point was unexpected. Given this large range in grain size, a high degree of sediment transport specification is necessary. From the model sensitivity tests the Van Rijn's (1984ab; 2007ab) transport formula were selected as the sediment transport equations for bedload and suspended load in CMS-Flow.

For this study, the CMS was validated by comparing the available field data with the calculations. To demonstrate model skill, the goodness of fit statistics was applied (CIRP, 2010),which include the Root Mean Square Error (RMSE), the Normalized Root Mean Square Error (NRMSE), and Correlation Coefficient for hydrodynamic variables, and the Brier Skill Score (BSS) for morphology change.

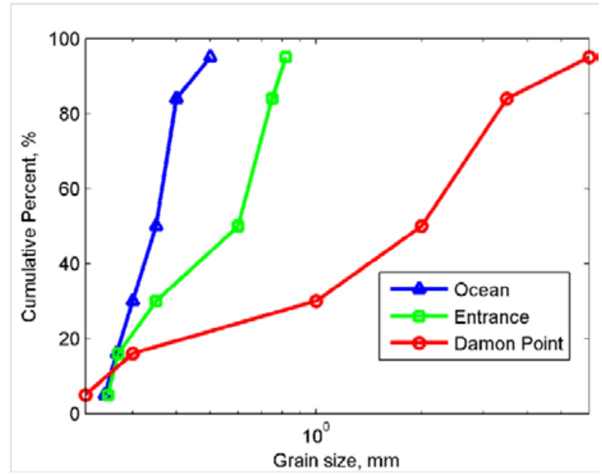

Fig. 6. Grain size variability in Grays Harbor.

RESULTS AND DISCUSSION

Validation of Hydrodynamics

Model validation was first performed using the water level, depth averaged current, and wave measurements at the gauges near Damon Point (Fig. 2).

Calculated water levels were compared to ADV265 located on the north western end of Damon Point and the nearshore ADP located near the midpoint of the spit (ADPM135) and the results are shown in Fig. 7.

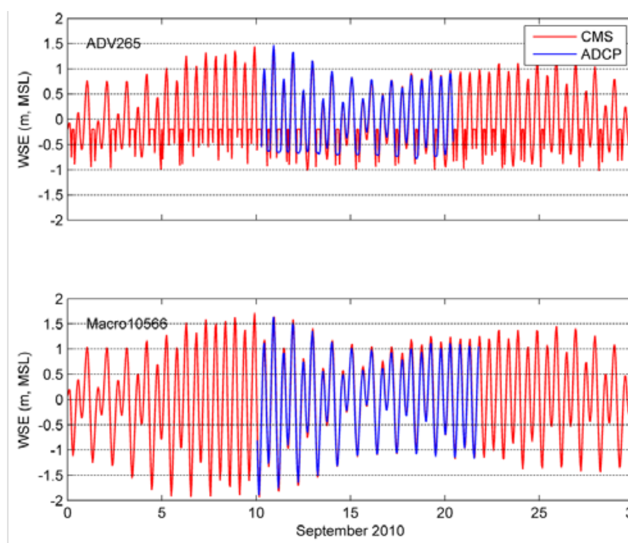

Fig. 7. Water level comparisons between the CMS results and the 2010 field Data.

Table 1 shows the goodness of fit statistics between the measured data from the 2010 field data collection and the calculations.

Table 1. Water level goodness of fit statistics: 2010 field data.

Gage	R^2	RMSE (m)	NRMSE (%)
ADV265	0.933	0.209	8.4
ADPM135	0.992	0.101	2.9

Calculated and measured depth averaged current velocities were compared with all three gauges near Damon Point. Fig. 8 shows the current velocity comparisons between the measurements and calculations and Table 2 details the goodness of fit statistics for all three gauges.

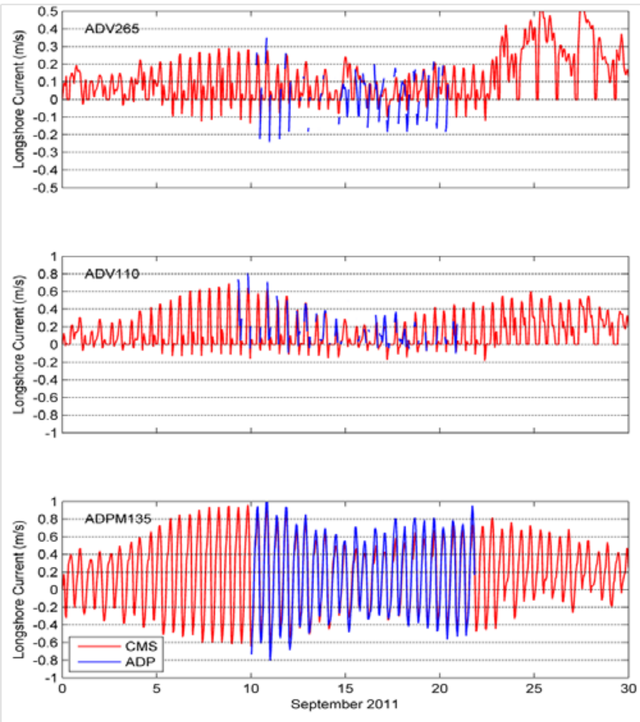

Fig. 8. Current comparisons between the CMS results and the 2010 field Data.

Table 2. Current velocity goodness of fit statistics: 2010 field data.

Gage	R^2	RMSE (m)	NRMSE (%)
ADV265	0.618	0.101	16.8
ADV110	0.709	0.142	14.2
ADPM135	0.971	0.128	7.1

The strongest correlation was for the nearshore ADPM135 while the ADV 265 showed the weakest model validation. This performance is most likely due to a combination of the model limitations with regards to currents and the location of ADV265 which dries at low tide. The model does not calculate the vertical profile of current velocities.

Wave validation was performed for both ADV 265 and the nearshore ADPM135. Validation results are provided in Fig. 9 and Fig. 10 while goodness of fit statistics is detailed in Table 3 and Table 4. Wave parameters include wave height (top), wave period (middle) and wave direction (bottom). Wave direction was not measured for the nearshore ADPM135 but the calculated values are provided in the bottom panel for reference.

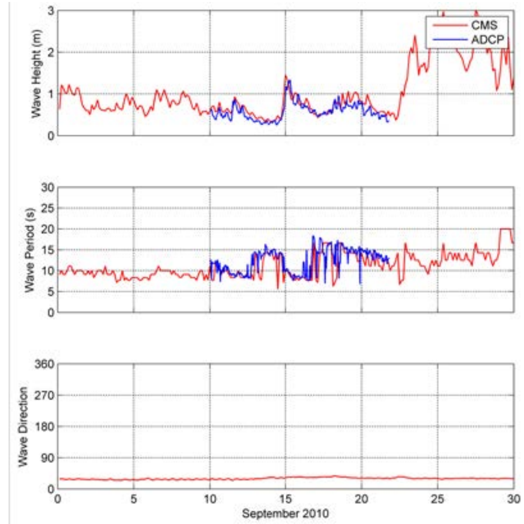

Fig. 9. Wave parameter comparisons between the CMS results and the 2010 field Data at ADPM135.

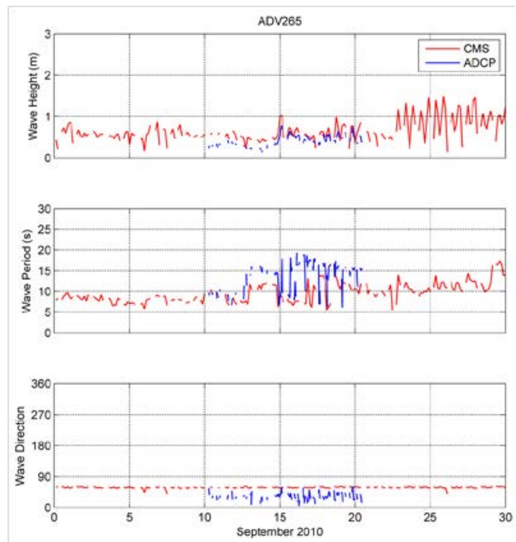

Fig. 10. Wave parameter comparisons between the CMS results and the 2010 field Data at ADV265.

Table 3. Wave goodness of fit statistics: 2010 Field Data at ADPM135.

Wave Parameter	R^2	RMSE (m)	NRMSE (%)
Wave Height	0.841	0.156	10.4
Wave Period	0.644	2.679	14.9

Table 4. Wave goodness of fit statistics: 2010 Field Data at ADV265.

Wave Parameter	R^2	RMSE (m)	NRMSE (%)
Wave Height	0.722	0.199	24.9
Wave Period	0.232	5.419	30.1

Validation of Morphology Change

Fig. 11 compares the measured and calculated morphology change covering the vicinity of the inlet, Damon Point and Half Moon Bay. Warmer colors indicate sediment deposition while cooler colors represent erosion. The major morphologic features are represented although the magnitude and location of the bed change may vary. For example, the model properly simulated the growth of the bar at the distal end of the Damon Point spit although its shape is not exactly correct. The model captured the shoaling hotspot in the navigation channel near the south jetty and Half Moon Bay. Erosion of the inlet entrance and accretion on the ebb shoal are also captured by the model. Some of the differences may be attributed to errors in the initial and final measured bathymetry and initial bed composition.

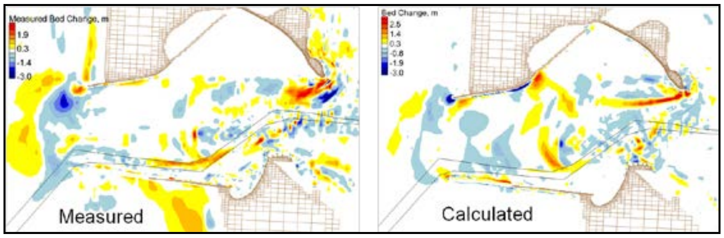

Fig. 11. Morphologic comparison between the measured (left) and the calculated morphologic change (right): 2010 field data.

Fig. 12 shows the location of transects along the shoaling hotspot in the navigation channel located near the south jetty and Half Moon Bay in the navigation channel and distances measured in meters moving north to south. The bathymetry shown in the figure indicates the presence of a large sand wave which is migrated south-west onto the navigation channel and is believed to be the major source of the channel shoaling in that region. Sand waves in this region of the entrance have been reported by USACE (2005). Fig. 13 shows the initial and final computed and measured water depths for each transect and the associated BSS values that range from 0.03 to 0.65. The best performance was observed for transects 1, 2 and 5 while the remaining transects showed poorer performance. The model consistently under-predicted the channel shoaling throughout the section of the navigation channel. This is primarily due to the fact that the model does not simulate sand waves and tends to smooth them out.

Fig. 12. Transect locations for morphologic validation.

Sediment Transport

Fig. 13 shows the wave height and vectors for the inlet. Warmer colors indicate larger wave heights while cooler colors indicate lower wave heights. The color bar extends a range from 0 to 2 m wave heights. Wave vectors indicate direction. Even though offshore waves are propagating from the northwest, a significant amount of wave energy is refracted towards Damon Point spit. Similar wave focusing at Damon Point was observed by USACE (2006). The wave focusing is partially responsible for the net south-easterly sediment transport along Damon Point and the retreat of the seaward shore of Damon Point as demonstrated by historical shoreline evolution (Golder 2010).

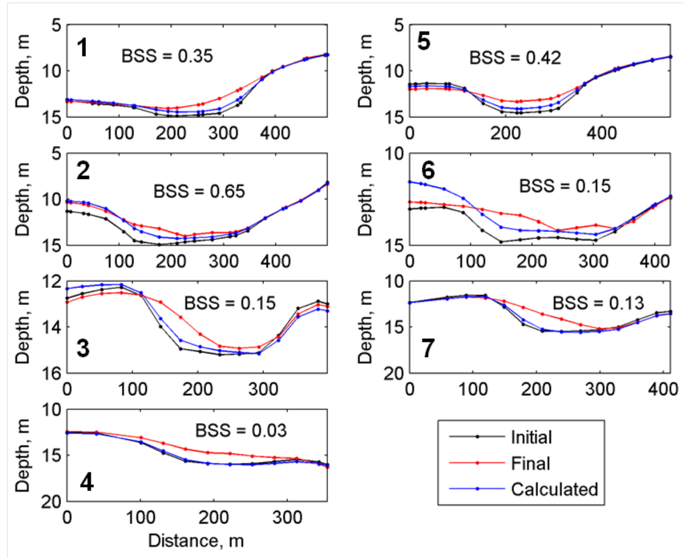

Fig. 13. Morphologic validation and BSS values: 2010 Field Data.

Fig. 14 illustrates the present understanding of sediment transport pathways, a net landward (flood) sediment transport in the northern half of the entrance, a seaward (ebb) transport in the southern half, and a bimodal transport along the inlet center axis. The calculated sediment transport pathways from this study are provided in Fig. 15 and roughly match the previous conceptual pathways. The vectors of sediment transport are overlain on bathymetry and topography contours. Vector length indicates relative sediment transport magnitude. The flood pathways are captured near the northern half of the entrance channel and the transport from the distal lobe of Damon Point is also represented. Ebb pathways are represented through the channel. However, the net landward (flood) transport in the northern half of the entrance near the north jetty following the shoreline is not observed.

Fig. 14. Conceptual sediment transport pathways.

The calculated net total-load sediment transport rates roughly follow the conceptual pathways in Fig. 14 and the calculated pathways in Fig. 15. Vectors and color gradient represent net total load of sediment transport in kg/m/s in Fig. 16. The maximum observed sediment transport rate in this figure is 0.15 kg/m/s near the distal lobe of Damon

Point and near the seaward ends of the jetties. The observed offshore (ebb) movement near the placement site adjacent to the south jetty is represented in Fig. 16. Sediment transport into the system is shown running along the north jetty but is less in magnitude than the movement off of the distal lobe of Damon Point into the channel and out of the inlet. Alongshore transport on either side of the inlet is also represented and corresponds with the known direction of alongshore sediment transport.

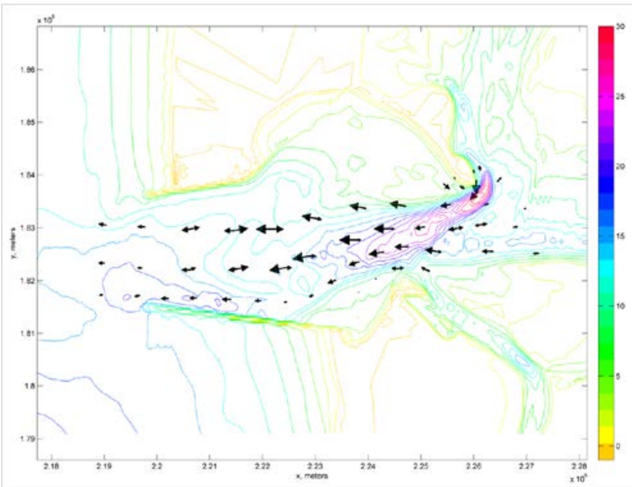

Fig. 15. Calculated sediment transport pathways.

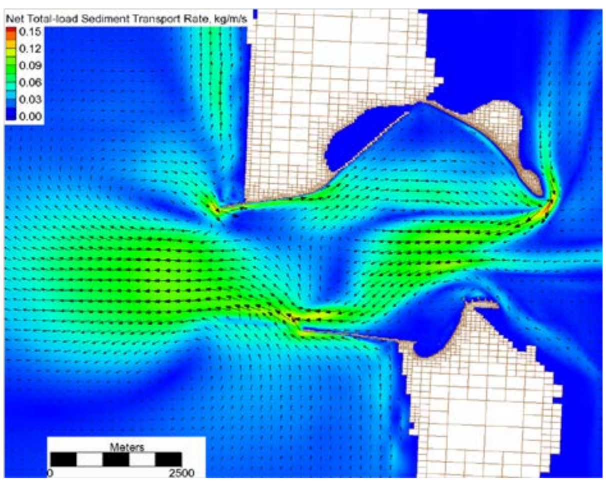

Fig. 16. Net total load sediment transport rates.

Fig. 17 shows the gross total load sediment transport rate (kg/m/s). Warmer colors indicate larger magnitudes of gross sediment transport while cooler colors indicate smaller values. Most of the sediment movement is centered around the area between the jetties north of the navigation channel. Interestingly, this same area has relatively small net transport rates as shown in Fig. 16 and is known to have active sand waves (USACE 2005). The presence of large sand waves and gross sediment transport rates in center of the entrance suggests that this area is not a good location to place the navigation channel. The gross sediment transports from the distal lobe of Damon Point is relatively large but not in comparison to the area between the jetties.

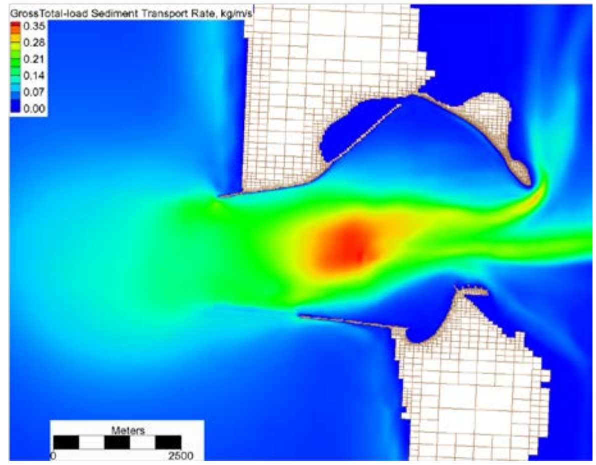

Fig. 17. Gross total load sediment transport rates.

Hypothetical Cases

Once the model was validated to field data, alternatives were investigated. A number of hypothetical cases have been run simulating a breach of Damon Point, the formation of a small spit and an extreme spit. The base bathymetry used for all hypothetical cases was collected in September 2010. The model results for these cases are described in the following.

Damon Point breach. From the geomorphic analysis performed using historic shorelines and measured morphology change, there is a concern that Damon Point would breach at the north western end. The purpose of this hypothetical case is to investigate the potential hydraulic and morphologic effects that a breach would have on the site. A breach was artificially created in the grid at the north western side of the distal lobe. The location and initial bathymetry of the breach is shown in Fig. 18.

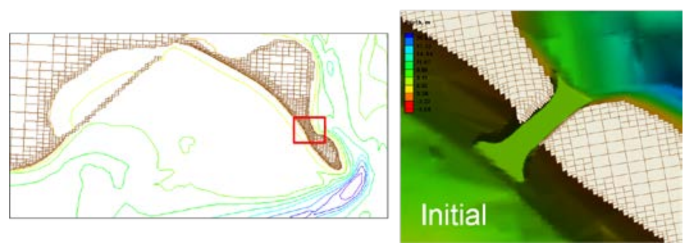

Fig. 18. Hypothetical breach: location of breach (left), Damon Point breach grid setup (right).

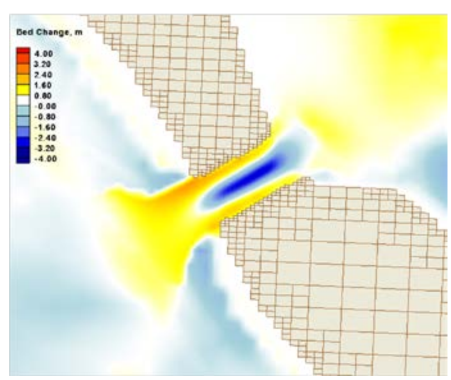

Fig. 19. Calculated morphology change due to hypothetical breach.

A difference plot of morphology change is shown in Fig. 19. Warmer

colors indicate sediment accretion and cooler colors represent erosion. After a one month, the simulation indicated that the breach continues to deepen up to 3.25 m.

Damon Point small spit. This hypothetical case added material to the distal lobe of Damon Point extending the point by 68 meters in order to simulate anticipated bar growth. Fig. 20 shows the initial grid bathymetric set up and Fig. 21 shows a difference plot of the calculated morphology change. Warmer colors indicate sediment accretion and cooler colors indicate erosion.

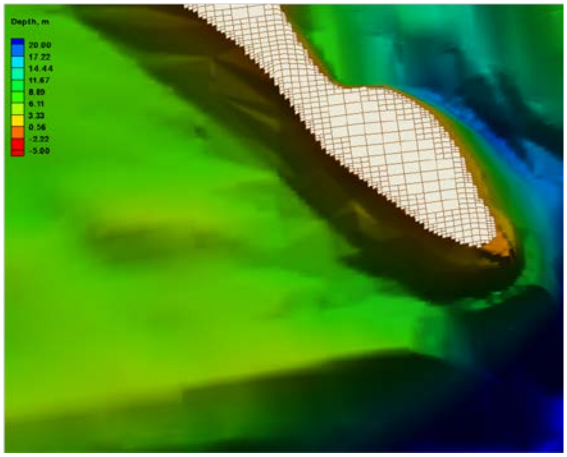

Fig. 20. Hypothetical case: small spit setup.

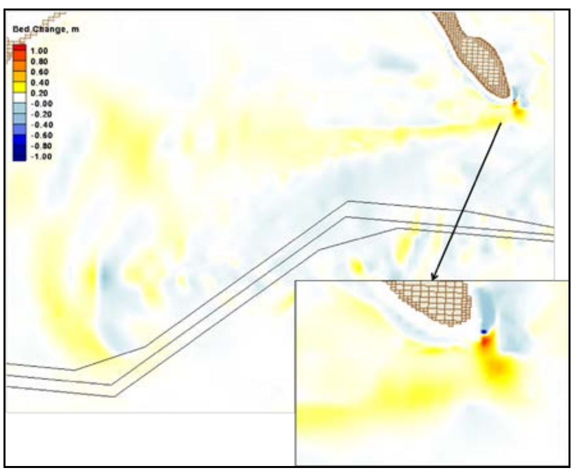

Fig. 21. Morphology change due to hypothetical small spit.

The results showed little change from the existing condition which indicates that the small spit isn't having a large affect on the hydraulics of the system.

Damon Point Extreme Spit. The intention of this simulation is to continue the spit simulation to see if a dynamic equilibrium could be reached. The grid set up for this case is shown in Fig. 22. Material was added to the distal lobe of Damon Point to simulate the anticipated bar growth. A spit was created artificially from the lobe approximately 200 m in length and the simulation was run from this point onward. The initial bathymetry for this case was generated from the final bathymetry of a 3 month winter simulation. An additional 3 months were run from this point with a morphologic acceleration factor of 3 resulting in a total simulation time of 9 months. The initial and final 9-month bathymetry is shown in Fig. 23.

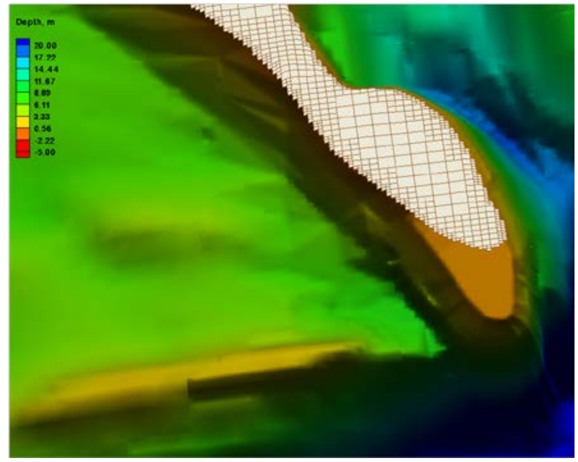

Fig. 22. Hypothetical case: extreme spit setup.

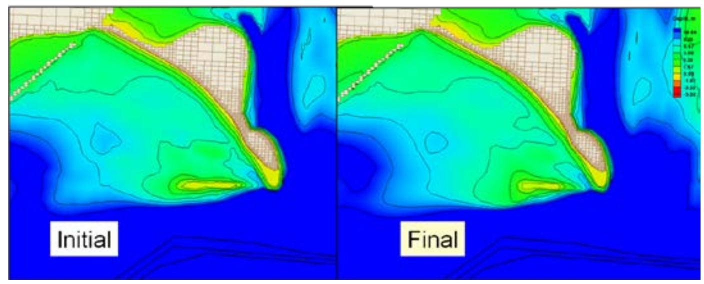

Fig. 23. Extreme spit: 9 month morphology change.

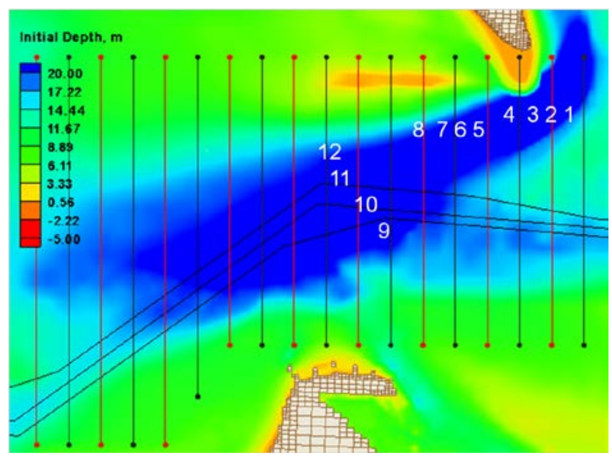

Fig. 24. Hypothetical extreme spit transect locations.

In order to examine the differences in morphology change as a result of the extreme spit, a series of transects were taken to compare the calculated bed changes between the existing condition to the calculated extreme spit case. Fig. 24 show the locations of transects used to analyze the bed change from existing to the extreme spit conditions. Comparisons are made for the bed changes in the transects between the extreme spit condition and the existing condition.

Areas which showed the most movement change were over the bar that extends from the distal lobe of Damon Point parallel to the navigation channel. Given the previous modeled and measured observations of sediment pathways, it's most likely that the sediment is being moved out through the inlet. Portions of the transects that cross the navigation channel did not show large changes in bathymetry change between the existing condition to the extreme spit case.

CONCLUSIONS

The evaluation of the geomorphology changes of Damon Point over time through the GIS analysis and morphodynamic modeling in CMS indicate that the spit will most likely breach and detach entirely from Ocean Shores. This breach could occur gradually over time or during a storm. Another potential breach location is the base of the neck of the distal lobe.

Spit growth is caused by convergence of net transport on the shoreface and bay sides of Damon Point. Wave induced currents combine with flood dominant tidal currents on the shore face side of Damon Point to produce net southeasterly transport. Deeper depth contours are represented by cooler colors and warmer colors indicates shallower depths.

The spit is limiting sediment supply to the North Bay by continuing the build the distal lobe of Damon Point, the formation of a bar adjacent to the spit and the southeast migration of the channel thalweg. It is anticipated that the spit will continue to grow, however, the long-term evolution cannot be presently simulated with our present technology. Constriction of the ebb currents by the growing spit has limited the transport of sediments into the Northern bay, increased the growth rate of the spit and formed a large bar adjacent to the spit.

In order to investigate potential effects of the anticipated morphological evolution of Damon Point, several hypothetical cases have been simulated. In all cases, there was not an appreciable increase in shoaling within the navigation channel.

It is expected that the spit will continue to grow, however, long term evolution cannot be accurately simulated without significant assumptions about the forcing climatology and morphologic acceleration factors. Damon Point does not yet have a significant impact on existing dredging operation and maintenance activities and is not expected to influence those activities in the mid-term (1-5 years). It is recommended to monitor the spit and the nearby bathymetry and conduct additional simulations. If a breach occurs at the neck of the distal lobe, its fate will depend on sources of sediment and wave and flow conditions subsequent to the initial breach.

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